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TR-1239

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A PROCEDURE FOR DEVELOPMENTAL DROP-TESTING SAFETY AND ARMING MECHANISMS CONTAINING TIME-INTEGRATION SYSTEMS

Arthur Hausner

25 June 1964

HARRY DIAMOND LABORATORIES
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ARMY MATERIEL COMMAND
WASHINGTON 25, D.C.

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(5) Conduct basic research in the physical sciences, as directed by the Director of Research and Development, AMC.

(6) Perform basic and applied research on fluid amplification and control and development of pure fluid devices and systems.

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(a) Proximity fuzes, radiating or influence field.
(b) Time fuzes, electrical, electronic, delay, or fluid.
(c) Selected command fuzes.

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UNITED STATES ARMY MATERIEL COMMAND
HARRY DIAMOND LABORATORIES
WASHINGTON 25, D.C.

DA-1P523801A300 TR-1239
AMCMS Code 5523.11.62400
HDL Proj. No. 46300 25 June 1964

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This report was previously issued as HDL Report R-320-61-4, February 15, 1961.

FOR THE COMMANDER:
Approved by
Robert S Hoff
Robert S. Hoff
Chief, Laboratory 400

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ABSTRACT

The general ordnance developmental drop-test program is discussed with an aim toward establishing a procedure for drop-testing time-integration systems in safety and arming mechanisms. An attempt is made to justify use of impact media that give rise to approximately constant acceleration-time characteristics as being the most practical means of insuring safety for a given drop height and, at the same time, of providing the most reliable index of safety that can be experimentally determined. An example of how the procedure is used is also described.

1. INTRODUCTION

Accidentally dropping live fuzes has always been considered dangerous because of the possibility of detonation. In general, when it was felt that damage could be severe, such as the destruction of a ship and its contents, rigorous tests were devised to insure safety. MIL-STD-302, "Forty (40) Foot Drop Test for Use in Development of Fuzes," (ref 1), was in fact designed because of the "free fall possibility of a fuzed projectile, bomb or other round during handling from dock to ship, or the possibility of between-deck falls on shipboard." In recent years, however, there has been a growing awareness among fuze engineers that MIL-STD-302 is inadequate for insuring the safety of a fuze after a 40-ft drop. Fuzes containing time-integration mechanisms (arming by use of setback forces) for safety have been shown to be more susceptible to arming when dropped on materials other than the steel specified in MIL-STD-302. This fact, known for some time, has influenced developmental as well as production drop-testing of fuzes. At the discretion of the engineer, fuzes are subjected to many varied tests.

The admitted necessity of these nonstandard tests and concern about whether or not these tests proved the drop safety of fuzes prompted two investigations, both initiated by Picatinny Arsenal. The results of these investigations are reported in references 2 and 3.

Reference 2 analyzed the handling of ammunition currently used throughout the world. The significant conclusions, as stated in the abstract were ". . . that ammunitions (bare as well as packed, and fuzed as well as unfuzed) may be exposed to a possible accidental drop at any height up to approximately 100 ft, at any altitude, onto any medium of practically any impact characteristics."

Reference 3 was a study of impact acceleration-time characteristics of five different rounds, each dropped twice onto five different materials from heights of 25, 50, 75, and 100 ft. The resulting 200 curves were then analyzed in an effort to improve MIL-STD-302. The results of the analysis found that impacts on steel, wood, and sand

rendered peak accelerations and time-pulse ranges that overlapped and were fairly broad in scope, covering 40 to 18,000 g in pulse times of 40 to 0.3 msec. Based on these reports, four major revisions of MIL-STD-302 were recommended, as follows:

(1) Change the required height of drop from 40 to 100 ft.

(2) Expand the test to include drops on wood and sand as impact media for time-integration mechanisms.

(3) Expand the test to include a packaged fuze drop.

(4) Consider that a fuze has failed the test if even one sample arms.

These four recommendations were submitted to the Joint Army-Navy-Air Force (JANAF) Fuze Committee for adoption and the establishment of a revised MIL-STD-302. The fuze committee, after considerable study, rejected the recommendation pending further study. Appendix A contains the pertinent portion of the rejection letter, which clearly explains the reasons for rejection as well as the committee's recommendations for further study.

The subject of safety in ordnance designs is probably the most debated problem of fuze designers. The problem usually revolves about the question: "How much safety should an engineer put into a particular ordnance design?" There are so many facets to this problem that one can hardly hope to solve it without intensive research. Even then, it is most difficult to predict how a particular safety or lack of safety might affect a war effort. Moreover, human factors are involved which cannot be evaluated on the basis of expediency. Reference 4, referenced in paragraph 6, Appendix A, makes a good attempt to analyze the safety problem. However, it seems unlikely, as implied, that the relative danger of an accidental drop (or a situation in which a projectile undergoes an accidental velocity change) might be small enough to warrant the elimination of drop-testing, and it seems unlikely that any analysis could do this. It rather would seem that drop-testing is necessary and is here to stay, although further study as indicated by paragraph 11b, Appendix A, might show that different drop heights (or velocity-change requirements) should be used in drop tests for different types of ammunition; i.e., different types of ammunition should be impact tested in a different way because of different handling conditions. This problem, therefore, cannot be solved by a test at one fixed height (or fixed velocity change of shell due to impact); it may be possible, however, to standardize a procedure.

This report describes and attempts to justify a procedure of drop-testing that has been used in HDL fuze safety evaluations for time-integration setback mechanisms. It is written with the aim of presenting data and the critical parameters that are requested in paragraphs 11a and 13, Appendix A, and that might lead to a useful standard procedure for developmental drop-testing.

2. CONCEPTS OF DROP-TESTING

In establishing a procedure for drop-testing developmental arming mechanisms, one can usually assume that complete hardware, package, etc., will not be available until an arming mechanism design is completed and built. Therefore, such developmental drop tests as are established must rather insure that the completed fuze, packaged or not, can pass rigid production drop tests. If the drop test cannot insure this, then expensive redesign for drop safety may be necessary. The history of two fuzes, the M517 mortar proximity fuze and the M211 rifle grenade, serve to illustrate the enormous expense in time, money, and curtailed usefulness that can be involved. For this reason, it would seem much more desirable to insure the drop safety of an arming mechanism, independent of other fuze components or packaging and, preferably, to have some index of safety so that the degree of safety can be known. This independence should be required of any developmental drop-test procedure that is contemplated and has been so done in development procedures at HDL. The procedure thus minimizes the probability of a "bad" design showing up in a production fuze. Package and fuze-in-round tests are, of course, invaluable and necessary when possible, but are more in the nature of production tests since they can only be made in the pilot production stage of a fuze.

Bearing this in mind, the recommendation made by Rheem Manufacturing Company in reference 3 regarding the dropping of packaged and fuzed rounds seems inappropriate. Also, to insure safety by dropping a fuze or package on steel, wood, and sand, and hope to duplicate conditions that would most likely cause arming involves a certain amount of risk, unless it can be proved by adequate measurements that impact accelerations on these materials include those to which a mechanism is known to be most sensitive. However, it would seem more appropriate to consider an obverse approach:

(1) Determine a class of critical acceleration-time curves that produce arming with a minimum velocity change. This is necessary if we assume that any acceleration-time characteristic is possible in accidental drops.

(2) Subject the proposed design to such critical acceleration-time functions with the minimum velocity change for which safety must be insured. (The minimum velocity change that will cause arming with the critical acceleration function is the safety index.)

The difference in approach is that one substitutes one acceleration-time function with which arming is most likely to occur for numerous functions that hopefully might include this function, hence, results can more confidently insure safety. If such a procedure is possible, and values are established for minimum velocity change requirements for arming under critical conditions (minimum safety index), then placing the mechanism in a fuze and/or the fuze in a package

cannot alter the results, since the mechanism will already have been subjected to the most critical conditions. The problem, then, is reduced to determining the critical acceleration-time curves and minimum drop-safety requirement.

3. CRITICAL ACCELERATION-TIME CURVES

It has long been known that the most critical acceleration which will arm a setback-leaf system corresponds to infinite acceleration pulses, each lasting for 0 time (an instantaneous velocity change) and each operating on one element of the system, supplying just enough energy to override the spring and frictional forces. The pulses must occur each time an element is released in sequence. This theory is covered adequately in reference 5. Clearly, such an acceleration-time curve is impossible, although it may be approached by a drop fixture crashing through successive steel plates or in a package in which supporting members fracture successively. In any case, the probabilities of such a package design or of such an impact surface for actual handling conditions is so small that to design a drop test obtaining this condition would seem unnecessarily severe.

Actual acceleration-time curves produced by dropping rounds on different media (ref 3) show the enormous variety of curves that can be expected. Some are practically constant; others are sinusoidal or triangular in shape; many have vibrations superimposed on curves; still others are so irregular as to defy a simple general description. One must choose, however, a realistic acceleration-time curve that requires a smaller velocity change for arming than most other curves. To do this, some understanding of the nature of setback leaves is necessary. Reference 5 discusses them in detail, and only a brief description will be given here.

Most time-integration systems used in fuzes consist of mass-spring elements interlocked in a way such that operation in a particular sequence is necessary. Acceleration overcomes spring and frictional forces, and moves an element into a position such that further acceleration can move the succeeding element. Each spring is stressed to begin with, and frictional restraining forces are present, so that a minimum acceleration, say Ng, is required to start the element moving.

One can at once require that the acceleration curve attain at least this minimum in the shortest possible time so that, the first leaf will begin its motion as soon as possible. In order to insure the same requirements on the second leaf, one must maintain the acceleration value above Ng. If one permits vibrations to carry the acceleration below Ng, arming depends on proper timing of vibration and leaf release. Probabilities of proper timing in an actual drop are small enough to warrant the exclusion of such an acceleration curve in a standard test where one wants a high arming probability

if arming is indeed possible. For the life of the curve, therefore, one must specify values of at least Ng.

Therefore, it seems best to select a constant acceleration as a practical test condition for the following reasons:

(1) Simplicity.

(2) Many natural impact accelerations are approximately constant.

(3) Other acceleration functions acting on one element for an interval can usually be approximated by a linear function, and it is shown in Appendix B that there is only a small difference in velocity change requirements for arming with a linear acceleration above Ng and for arming with its average constant, for most cases.

If it is accepted that a constant acceleration is a good standard to use, it is easily proved that an arming mechanism is most sensitive to a constant acceleration of 2 Ng (ref 5) (Appendix C). This criterion then, will be our initial choice, and is the basis of the procedure to be outlined. Experimental data will also be given to show that the criterion is severe enough to make it a practical standard in developmental drop-testing; i.e., if a mechanism is shown to be safe for a constant 2 Ng acceleration experienced on impact, it becomes unlikely that impacts on media in general will arm it with the same velocity change.

A simple method of obtaining a constant acceleration in a test is to use a centrifuge.* However, a safety evaluation using this method must be rejected, since a centrifuge time test is physically quite different from an impact resulting from accidents. There are close resemblences between the two situations, but other effects occurring during impact, such as vibration, are not duplicated. Therefore the desired confidence in results requires a dynamic test.

A homogeneous substance that deforms easily if impacted by a missile usually absorbs energy from the missile proportional to the volume of the substance displaced by the missile. The significance

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* Centrifuges are in fact used to obtain arming times of developmental models of time-integration mechanisms at constant acceleration. It is an excellent aid in the early design stages since it can be used to check the minimum velocity change that has been calculated from theory and can hence guide the designer to more accurate calculations. With the centrifuge data, the minimum velocity change is merely the minimum product of the acceleration and the arming time.

of this fact is that if the missile is a cylinder, constant accelerations result. This has been experimentally proved at these laboratories for lead, and undoubtedly is true for many other substances. This property of materials is basic to our concept of drop-testing.

4. PROPOSED DROP AND IMPACT TESTING PROCEDURE

The proposed procedure for drop-testing is divided into two parts; as has been done in the past.

(1) A drop test of 40 ft and even higher on steel is made to determine structural weaknesses in both developmental and production models as oversimulation of impact acceleration is obtained. For development models, the test would be used only to insure that the model is sufficiently rugged and to insure safety of the unarmed explosive train. This portion is similar to MIL-STD-302 and will not be discussed here.

(2) For time-integration mechanisms, the acceleration level for the most critical direction of drop is determined as described in reference 5. In a multiple-element system, each element may have different spring biases; the acceleration level required of the largest is chosen. A fixture is adapted to the mechanism and is impacted on any material that deforms easily and inelastically. If gravity is used to obtain the impact velocity, then it can be shown that the ratio of the height of drop H to the depth of penetration h into the medium is equal to the impact acceleration in g's if the acceleration-time curve is constant. If not constant, we can define H/h to be the average impact acceleration in g's. Then parameters are estimated so that $H/h = 2N$. To be sure, this value is best if the impact acceleration is constant; i.e., a maximum number of elements will operate, and arming is most likely if possible at all with a constant impact acceleration of this value. Actually, the acceleration is not exactly constant and may deviate depending on the material used. Figure 1 is a graph showing the dependence of the minimum velocity change required for arming on the applied constant acceleration g. Inasmuch as minimum velocity change indicates sensitivity, a system is much more sensitive to accelerations of about 2 Ng than to acceleration either below or above 2 Ng. However, to account for frictional variations, or a possible miscalculation of N, more than one value of H/h should be tried. It is customary, in fact, to increase the value of H/h from N and continue testing until one less element is operated, or arming does not occur. We will therefore pass through the most sensitive value of H/h for the design under test. The number of elements operated can be observed by a suitable indication mechanism.

The above is essentially the procedure that is recommended as a developmental drop test to insure safety with any drop of, say, 40 ft. If higher velocities are desired to insure safety

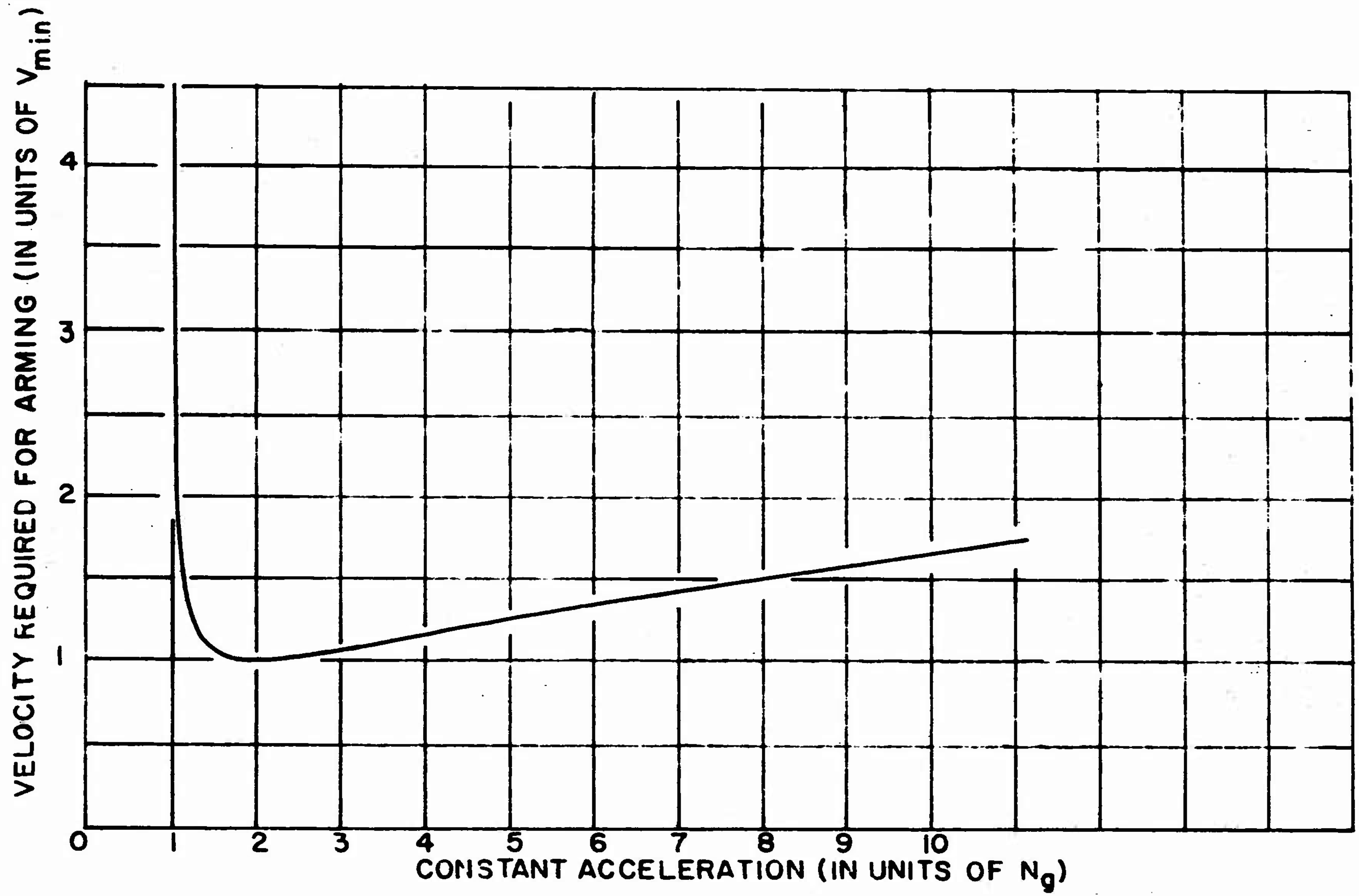

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Figure 1. The dependence of the velocity change required for arming on an applied constant acceleration.

for drops from higher heights or to determine the safety index (the minimum velocity change required for arming) an accelerating machine such as an air gun can be used. Impact can occur into lead, wood, firm earth, sand, or, in short, anything that deforms fairly inelastically, The choice of material depends mostly on the convenience involved due to the impacting fixture. For example, if a heavy object is tested and accelerations of 500 g and above are required, then dropping in firm earth or sand will be inappropriate as the acceleration will be small because of a relatively large depth of penetration. In general, then, the material will be suited to the fixture and/or the fixture, to the material.

By way of illustrating the procedure, let us take a mechanism developed and drop-tested at HDL and examine the procedure and problems involved more closely. Figure 2 shows the basic mechanism, designed for operation in a spinning munition by using the centrifugal forces developed. About 25 g acting radially at the center of mass of the elements will create the following motion: leaf 2 and leaf 1 will alternately rotate outward as each positions itself at the successive stop or impact position. Only one element can move at a time because of the "zig-zag" nature of leaf 2. This stopping of one element by the other creates an effective five-element system by definition, that an element in a time-integration system is one that starts from 0 velocity and moves to a position to permit another element, starting from 0 velocity to move. Leaf 2, by its final motion, permits the release of a stab mechanism, which, of course, is the final objective. Safety consideration dictates the prevention of the release accidentally.

One possibility would be an accidental drop in the direction A which would create radial components of acceleration tending toward arming. This design was the fifth attempt to obtain adequate safety which illustrates the importance of a developmental drop-test without an entire fuze or package. The previous four designs were found to arm with a drop of less than 10 ft and were considered unsafe. These designs and tests are described in reference 6.

Figure 3 shows the drop-test arrangement eventually used. The drop fixture was made especially for this unit and was compact and small, weighing about 3/4 lb. Little previous experience could be applied as to what material should be the impact target. The first item to be calculated was the direction of critical drop as outlined in reference 5. This being done, the unit was oriented in this direction and holes were drilled in the fixture to observe the interlocking area of the elements. Next calculated was the amount of acceleration required to start arming motion for this direction. The results were approximately 125 g for the first element and 135 g for each successive stop position. (The last motion was discounted as unnecessary in the evaluation.) The calculations did not include friction which would raise the values.

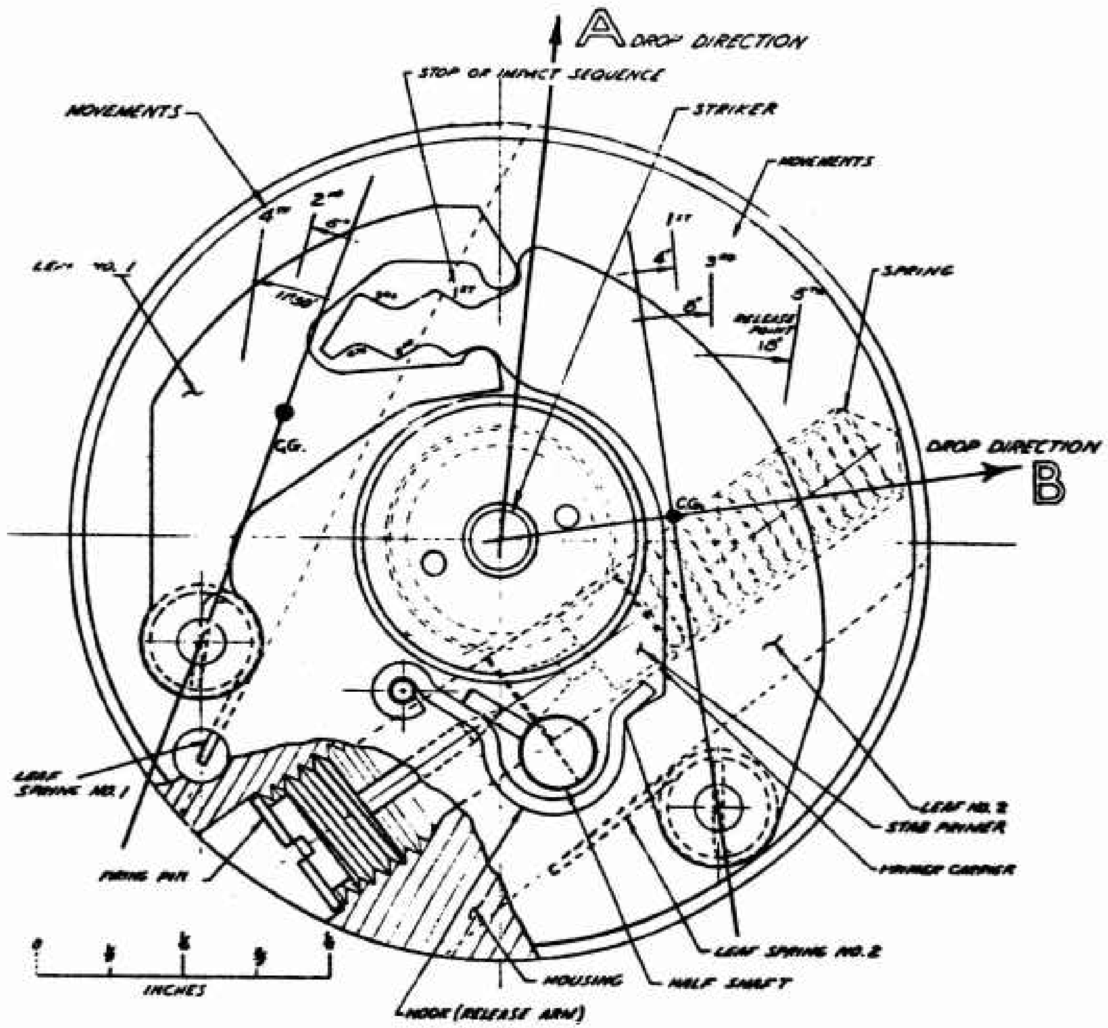

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Figure 2. Spin leaf system model no. 5.

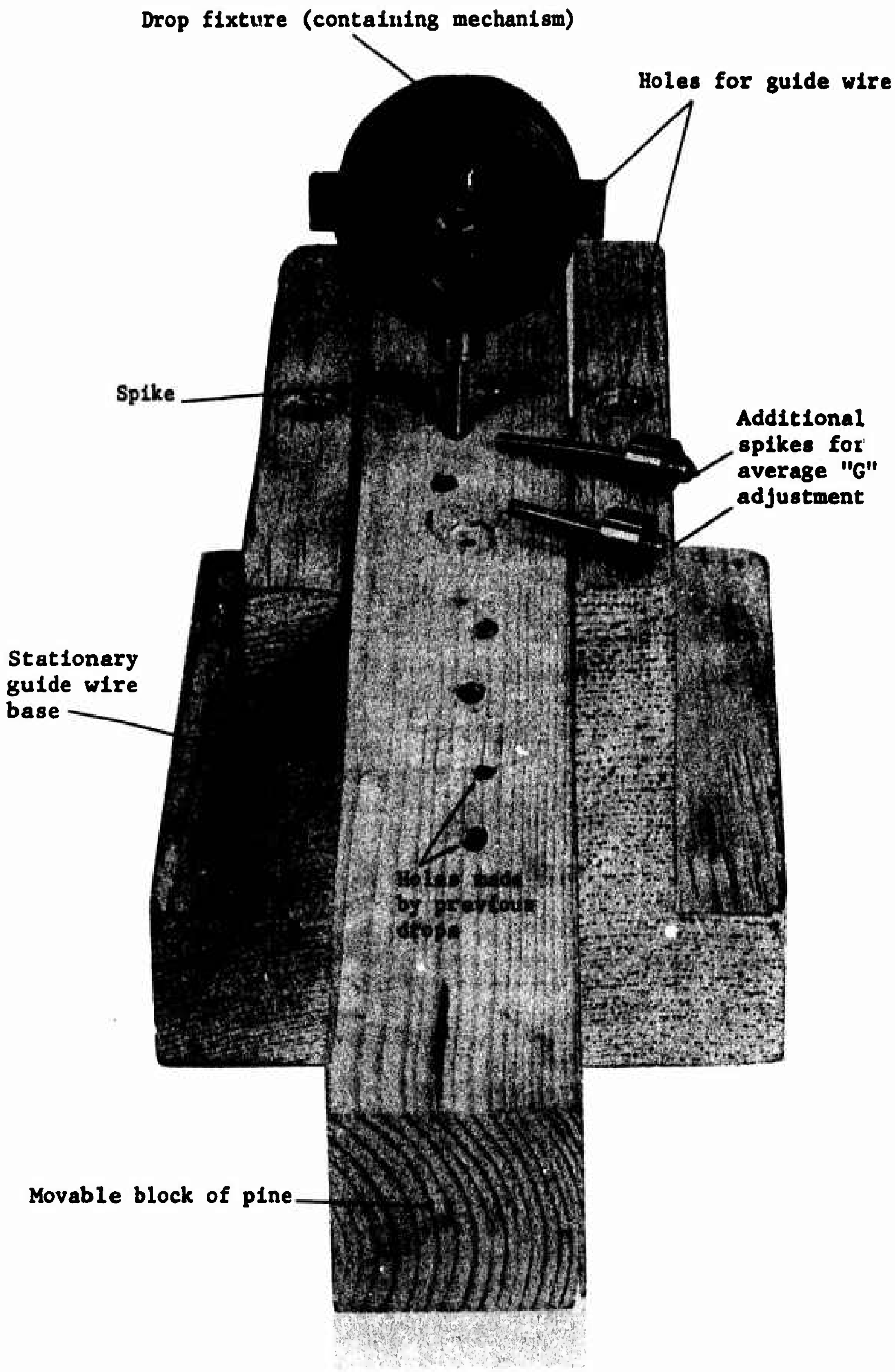

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Figure 3. Components used in drop-testing T1028 power supply initiator.

Therefore, 2N is at least equal to 270 g and would require for a 40-ft drop about a 1.8 in. penetration (maximum). A preliminary drop on sand showed a penetration from 10 ft of about 3 in., so that sand was excluded as an impact medium with the fixture shown. Instead, removable cylindrical spikes were fabricated and after some experimentation, it was determined that a 0.21 in. dia spike would produce an average of about 700 g when dropped 40 ft onto wood. (Yellow pine was used after experimentation with balsam wood.) A 0.15 in. dia spike produced an average of about 450 g.

The two leaves were smeared in the areas of contact with a lipstick that transfers easily. This served as an excellent indicator to determine by observation how many motions or impacts were completed. The following table contains the results:

Unit Number	Height of Drop	Spike Diameter	Depth of Penetration	H/h (Avg)	No. of completed Motions of Elem.
	(ft)	(in.)	(in.)		(Impacts)
2	10	0.21	0.15	800	1
2	20	0.21	0.32	750	1
2	30	0.21	0.54	670	2
2	40	0.21	0.72	670	2
4	10	0.15	0.32	380	1
4	20	0.15	0.50	480	1
4	30	0.15	0.86	420	1
4	40	0.15	0.91	510	1
4	10	0.21	0.15	800	1
4	20	0.21	0.37	650	1 *
4	30	0.21	0.45	800	1 *
4	40	0.21	0.66	710	1 *

*A second impact has observed at one of these heights. Lipstick transference was light and not observed until the unit was taken out of the fixture.

As can be observed, the depth of penetration was approximately proportional to the height which indicated fairly constant accelerations. Only one completed leaf motion was observed for 40 ft with H/h = 510, but two, with an H/h of 670 (unit 2) to 800 (unit 4). The test was not carried any further, contrary to the established procedure. H/h should have been made higher until only one completed leaf motion was again observed at 40 ft, in order to pass through the range of critical ratios. Engineering judgment, however, resolved that the unit was safe at 40 ft inasmuch as only two completed motions were observed whereas five were required for arming.

It must be pointed out here, that acceleration need not be acting on the last element throughout its motion to complete its travel. It is sufficient, rather, for only enough momentum to be given to the element to carry it to the final position. With this in mind, the above results can theoretically be predicted by methods described in reference 5 (Appendix C). Using the appropriate constants for the elements and taking N = 125, it can be shown that the absolute minimum velocity change requirements (using infinite acceleration pulses properly spaced) for the first two motions to be completed are 9.4 and 9.0 fps, respectively. These calculations imply that, if a constant acceleration is used as a driving force, then:

(1) At least one impact should be observed in all cases as tested, which is corroborated by the experimental results.

(2) For two impacts to be observed, a minimum velocity of about 30 fps is required.

(3) For three impacts to be observed a minimum velocity of 57 fps is necessary. (This would require about 50 ft of drop and agrees with the results in that no third impacts were observed from 40 ft.)

Since a 20-ft drop produces an impact velocity of 36 fps, it may be possible to obtain two impacts from this height, contrary to experimental results. It seems unlikely, however, considering friction was not included in the calculations. Actual minimum velocities would therefore be greater. Calculations showed a minimum velocity change requirement of about 100 fps to arm the unit. This could not be checked without the help of some accelerating machine to produce the velocity, but as modified by test results for other velocities gives a rough idea of the drop safety index.

6. GENERAL COMMENTS AND CONCLUSIONS

A safety index for any arming mechanism obtained by the above procedure can be very useful in determining package design, use limitation, etc., depending upon the degree of safety demanded by the tactical use of the weapon. By no means is the final fuze package limited to the velocity change index obtained with the mechanism alone; a package, in general, will increase velocity change requirements for a fuze because resulting accelerations will deviate from a 2-Ng acceleration, due to give or yield in the package. Felt padding, commonly used in packaging, for example, will compress during an impact, and a good deal of acceleration will be below Ng, wasting energy available for arming a setback system. These items can also be taken into account to arrive at some sort of safety index for a package. That the combination of fuze and package can be safer than fuze alone is evidenced by the fact that the M517 package rarely fails a 40-ft drop test whereas about 30 percent of particular production fuzes dropped individually will arm, even when dropped from as low as 35 ft on wood. (One production unit armed from a 25-ft drop on wood in a test at HDL. Production specifications call for drops on steel according to MIL-STD-302.)

The usefulness of the procedure can be measured by its advantages:

(1) Results can be interpreted with confidence and can be checked for consistency with theoretical calculations of safety index as well as with calculations from centrifuge data. One is assured that an experimental minimum velocity requirement is just that; guess-work is eliminated from the drop-test procedures.

(2) The results of such a procedure are independent of any velocity change requirement that may henceforth be established; i.e., they are independent of the results of any study that might be made on existing handling conditions, or methods of obtaining a velocity change. It is therefore in line with the comments and recommendations made by the JANAF Fuze Committee in Appendix A.

It is felt that the procedure is an excellent method of determining approximate impact safety in developmental stages of the design of a time-integration setback mechanism, and the principle could be incorporated among the military standard procedures.

7. REFERENCES

(1) MIL-STD-302 "Forty (40) Foot Drop-Test for Use in Development of Fuzes," 6 July 1951.

(2) "Ammunition Handling Study," Summary Report #R-159-133, Rheem Manufacturing Company.

(3) "Accelerometer and Drop-Test Studies and Recommendation for Revision of MIL-STD-302," Summary Report #R-159-19, Rheem Manufacturing Company.

(4) "Relative Accident Probability Analysis, "Navord Report 4135, U. S. Naval Ordnance Laboratory, 1 November 1955.

(5) "A Safety Analysis of Setback Leaves," by Arthur Hausner, NBS Report 16.5-6R, 24 April 1953.

(6) "Power Supply Initiator for the T1028 Fuze (U)," DOFL Report TR-616, by John Burke, 15 May 1958.

APPENDIX A. JANAF RECOMMENDATIONS FOR SAFETY DROP TESTS FOR USE DURING DEVELOPMENT OF FUZES*

"5. Adoption of the recommendations of the study and their effect upon design requirements has been considered by the JANAF Fuze Committee. It is difficult if not impossible to estimate immediately the time and cost of designing new fuzes or redesigning standard fuzes to meet the proposed requirements. Increasing the safety features generally tends to lower the reliability; hence, this matter should be considered in establishing new standards. Some of the standard fuzes may meet the proposed criteria.

"6. A review of the data supporting the recommendations of the proposed 100-foot drop test did not yield enough information to determine the expected frequency of drops in excess of 40 feet; the probability of the impact causing mass detonation or deflagration; the probable extent of loss in life, materials, and combat effectiveness from such explosions or fires; and the possibility of accidents as a result of using dropped ammunition subsequently in regular service use. Consecutive drops were not considered except to require that the fuze remain unarmed throughout the 100-foot drop and any resulting bouncing. The contractor gave no consideration in establishing the drop test, to the effects, conditions, and frequency of accidental impacts such as result from a rocket or bomb becoming free of the aircraft during arrested landing or crash on an aircraft carrier. As is indicated in the general discussion of the ordnance safety problem in reference (e) [Reference 4 in this report], any safety test program must attempt in an orderly fashion to detect all significant routes to accidents, and tests should be considered in the light of the overall contribution they make to determining the hazard potential of a fuze design or particular production lot. To the fuze, the impacts received in such landing accidents and in handling drops are similar in nature, if not in intensity.

"7. The standardization of a 100-foot free drop test requiring the construction of 100-foot towers appears to be unduly restrictive. The increase from the present test of a velocity change of about 50 fps (40-foot drop) to a velocity change of about 80 fps (100-foot drop) is a small increase in many respects. Should another increase be deemed advisable, either from consideration of other accident sources as mentioned in paragraph 6 or from changes in handling procedures, again new towers would be needed. An accelerating machine could readily produce a velocity of 80 fps without the construction of 100-foot towers, to replace 40-foot towers. Several

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* Portions of letter from Chairman, JANAF Fuze Committee to the Commanding General, Picatinny Arsenal, Dover, New Jersey, entitled "Fuzes; Safety Drop Tests for Use During the Development of." (Not dated, but written about December 1956.) The first four paragraphs present an introduction covering the two Rheem Manufacturing Company reports (ref 2 and 3) and recommendations summarized in the introduction of this report.

machines of this type are in use and the chief advantage is the opportunity to extend the test range beyond 80-fps velocity change as needed. . . .

"8. If certain ship loading operations are known to create an excessive drop hazard, changes in the handling equipment, procedures, and regulations might be more effective in reducing accidents than increasing the drop safety requirements of fuzes.

"9. The recommendation that drops be made in packaged condition as well as in the ordnance is considered important and experience supports this recommendation. The greater duration of impact, albeit of lower acceleration, resulting from package crushing has been found to be more effective in some cases, in causing fuze arming or malfunction than hard-surface impact and therefore is a highly essential part of a valid test program.

"10. The preparation of additional shock tests should be coordinated with the existing tests which produce varying degrees of shocks. The need for a test of fuzes in the packaged condition is recognized as mentioned above but a standard procedure should be established only after the limiting or critical parameters are established. Such an approach would tend to minimize the number of tests necessary to determine the safety features of a design.

"11. In consideration of the state of knowledge on this subject it is recommended that:

"a. No major modifications to the present Forty Foot Drop Test (MIL-STD-302) be made, except perhaps to call for in-package and soft-target tests of similar type to the present hard-target, steel impacts when data on the critical parameters are available. Further study of the problem may indicate the need for another drop test involving greater height, but the present test may be adequate for many types of ammunition and has the advantage of an extensive background of experience.

"b. Further study of the ammunition drop hazard be initiated and directed toward obtaining a better picture of the probability of dropping ammunition from heights greater than 40 feet, and the probable consequences of these accidental drops in terms of material losses and loss of life and military potential. It is believed that this type of information, obtained by supplementing the subject study with a study of accident experience, will form a better basis for a decision of whether or not to spend more in testing and designing fuzes for greater drop safety.

"c. Activities be reminded that, in development programs particularly, use of a particular MIL-STD is not mandatory nor desirable unless established as being necessary for the particular development and, conversely and more imperatively, that passing all MIL-STD tests does not automatically insure a safe design.

"d. Before adopting a new or different target the design of the impact target be studied to correct existing variables such as the foundation supporting the steel plate, the irregular surface of the plate after a few impacts, and the changing contact between the concrete and steel resulting from a dusting of the concrete and warping of the steel. Mounting of the targets on flexible systems with a low natural frequency as a means of securing greater uniformity in test conditions among test sites should be considered.

"e. If further study points to the need for a drop test from a height greater than 40 feet, accelerating devices be considered for use in obtaining the striking velocity rather than building towers high enough for gravity to produce the terminal velocity, and new design criteria for fuzes be established, setting forth the shock requirements to be met, not only for handling drop safety but for any other impact effects similar enough to be amenable to covering in a similar test, and a new acceleration (shock) test be devised which will produce repeatable conditions at a minimum expense.

"12. Since the study of ammunition handling and safety tests was initiated by the Ordnance Corps, it is believed advisable that the Ordnance Corps should continue or review the study to develop the information discussed in paragraph 11 above.

"13. The JANAF Fuze Committee has approved a "Five-Foot Drop Test for Use in Development of Fuzes" which should be published as a Military Standard in the near future. The committee is anxious to standardize any tests or procedures which show promise of becoming useful standards and the members will be pleased to receive additional data on the subject of drop shock tests. As in the past, Military Standards will be published when adequate data are available."

s/R. C. Daniel
t/R. C. DANIEL
Chairman

APPENDIX B

Comparison of Velocity Changes Required to Operate an Element in a Time-Integration Mechanism--Between a Linear Acceleration and Its Average Constant

A linear system will be considered. The results will approximately apply to a rotary element.

Consider an element in a time-integration system acted upon by a linear acceleration of the form

$$A = Kg + at \qquad \text{(K and a constants.)} \tag{B-1}$$

If t_ℓ is the time for the element to move to its release position, a distance X_r, it is clear that the velocity change required for arming, V_ℓ, is

$$V_\ell = Kgt_\ell + \frac{at_\ell^2}{2}. \tag{B-2}$$

Since the element is restrained by a spring of equivalent acceleration value Ng, then the effective acceleration acting on the element relative to the system is

$$A_s = (K-N)g + at, \tag{B-3}$$

from which clearly

$$X_r = \frac{(K-N)gt_\ell^2}{2} + \frac{at_\ell^3}{6} \tag{B-4}$$

From equation (B-2), the average acceleration $\bar{A}$ in the interval t_ℓ is $\bar{A} = Kg + \frac{at_\ell}{2}$. Applying this acceleration on the system gives rise to a time t_c for an equivalent motion, where the velocity change V_c for this constant acceleration is

$$V_c = (Kg + \frac{at_\ell}{2})t_c \tag{B-5}$$

and

$$X_r = \left[(K-N)g + \frac{at_\ell}{2}\right]\frac{t_c^2}{2}. \tag{B-6}$$

From (B-5) and (B-2), it is clear that

$$\frac{V_c}{V_\ell} = \frac{t_c}{t_\ell} \qquad \text{(B-7)}$$

and from (B-6) and (B-4), we have

$$\frac{(K-N)gt_\ell^2}{2} + \frac{at_\ell^3}{6} = \frac{(K-N)gt_c^2}{2} + \frac{at_\ell t_c^2}{4}. \qquad \text{(B-8)}$$

Using (B-7),

$$\frac{(K-N)gt_\ell^2}{2} + \frac{at_\ell^3}{6} = \frac{(K-N)g}{2}\left(\frac{V_c}{V_\ell}\right)^2 t_\ell^2 + \frac{a}{4}\left(\frac{V_c}{V_\ell}\right)^2 t_\ell^3 \qquad \text{(B-9)}$$

from which

$$\left(\frac{V_c}{V_\ell}\right)^2 = \frac{(K-N)g + at_\ell/3}{(K-N)g + at_\ell/2} \qquad \text{(B-10)}$$

From equation (B-10), the following can be ascertained:

(1) As $K \to \infty$, $V_c \to V_\ell$

(2) As $K \to N$, $V_c = \sqrt{2/3}\, V_\ell$ $(a > o)$

(3) Keeping in mind that as $K \to \infty$, then $t_\ell \to o$, from equation (B-4), we see that for $K > N$ and $a > o$,

$$\sqrt{2/3}\, V_\ell < V_c < V_\ell.$$

(4) If $a < o$ (a decreasing linear acceleration), then $V_c > V_\ell$. Just how much greater V_c will be depends on the values of the other parameters. Clearly, if $(K-N)g = -\frac{at_\ell}{2}$, then $V_c = \infty$; i.e., the constant average g will not move the element a distance X_r. This is true because $Kg + \frac{at_\ell}{2} = Ng$. The average constant is equal to Ng and the element will not move.

It is therefore concluded that only a decreasing acceleration can be more severe than a constant one. But practical accelerations obtained by dropping cannot consist of only decreasing segments. The effect will tend to cancel for a multiple-element system.

APPENDIX C

Minimum Arming Velocity Change

Reference 5 shows that a constant acceleration Kg acting on an element until it moves completely into position to permit motion of the succeeding element requires a velocity change V of

$$V = \sqrt{\frac{\phi K^2 g}{K-N}} \qquad \text{(C-1)}$$

where ϕ is a geometrical constant and Ng is the minimum acceleration required to move the element. By setting dV/dK equal to 0, it is determined that K = 2N will produce a minimum velocity change V_m, so that

$$V_m = \sqrt{\phi\ 4Ng} \qquad \text{(C-2)}$$

and

$$V = V_m \sqrt{\frac{K^2}{4N(K-N)}} \qquad \text{(C-3)}$$

Figure 1 is a plot of V and K from equation (C-3)

Reference 5 also shows that a constant acceleration acting on an element just long enough to give it sufficient momentum to be carried to the release position, requires a velocity change of

$$V = \sqrt{\frac{\phi KNg}{K-N}} \qquad \text{(C-4)}$$

Clearly, when $K = \infty$, V is minimum, and this corresponds to the infinite pulse of infinitesimal duration.

For a system with n similar elements, a constant acceleration need only act on the first n-1 elements throughout their motion and supply only momentum to the last element. The velocity change, therefore, required to move the last element to release position would be:

$$V = (n-1)\sqrt{\frac{\phi K^2 g}{K-N}} + \sqrt{\frac{\phi KNg}{K-N}} \qquad \text{(C-5)}$$

By differentiation, it is determined that the condition for minimum velocity is

$$(K-2N)^2\ K = \frac{N^3}{(n-1)^2} \qquad \text{(C-6)}$$

The following table is from equation (C-6)

Number of Elements	Constant Acceleration for Arming with Minimum Velocity (g)
1	∞
2	K = 2.618N
3	K = 2.328N
4	K = 2.224N
5	K = 2.170N
6	K = 2.137N
7	K = 2.115N
8	K = 2.099N
9	K = 2.087N
10	K = 2.077N

For a one element system, a drop on steel is most severe for an infinite pulse is desirable and will carry the element farthest. For more than one element, K becomes close to 2N with 2N as a lower limit. Hence, the criterion to keep the acceleration at least 2Ng is appropriate.

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A PROCEDURE FOR DEVELOPMENTAL DROP-TESTING SAFETY AND ARMING MECHANISMS CONTAINING TIME-INTEGRATION SYSTEMS - Arthur Hausner

TR-1239, 25 June 1964, 26 pp text, 3 illus, DA-1P523801A300, AMCMS Code 5523.11.62400, HDL Proj. No. 46300, UNCLASSIFIED Report

The general ordnance developmental drop-test program is discussed with an aim toward establishing a procedure for drop-testing time-integration systems in safety and arming mechanisms. An attempt is made to justify use of impact media that give rise to approximately constant acceleration-time characteristics as being the most practical means of insuring safety for a given drop height and, at the same time, of providing the most reliable index of safety that can be experimentally determined. An example of how the procedure is used is also described.

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